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CLINICAL REVIEW

Unattended home-based polysomnography for sleep disordered breathing: Current concepts and perspectives

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SUMMARY

Recently, portable sleep recording devices became an accepted alternative to polysomnography (PSG) for obstructive sleep apnea (OSA) diagnosis in patients with a high pre-test probability of moderate to severe OSA but home polysomnography (H-PSG) was not recommended because there were insufficient data.

The present review has analysed six prospective randomized crossover studies comparing H-PSG to in-lab PSG.

These studies convincingly showed that H-PSG allows complete sleep evaluation. The quality of patients' sleep tends to be better at home. H-PSG is accurate for OSA diagnosis and the failure rate is low despite the absence of supervision. In addition, it could offer a final and comprehensive diagnosis for many other sleep disorders.

It is also likely that H-PSG can reduce PSG-related costs but complete cost-effectiveness analyses are not yet available.

Recently, remotely attended H-PSG via telemonitoring has been tested and may reduce H-PSG failure rate.

In conclusion, H-PSG can be used to rule-in and rule out OSA in suspected patients, even in the presence of co-morbidities and is an alternative when simplified sleep testing is negative.

Future developments should target simplification of technical aspects of H-PSG, together with remote monitoring, in order to obtain good quality H-PSG performed in adequate conditions.

Introduction

Obstructive sleep apnea syndrome (OSA) is a major condition that is now recognized as an independent risk factor for hypertension and cardiovascular disease. It is characterized by repeated episodes of apnea and hypopnea during sleep usually leading to significant hypoxaemia, subsequent arousals with sleep fragmentation and reduced rapid eye movement (REM) and slow wave sleep. Guilleminault and colleagues were the first to describe this syndrome in 1976 [1]. Since then, awareness of this complex disease, and its consequences, has grown considerably. Prevalence is currently about 6–7% but this is probably an underestimate and numbers are likely to grow in the future as OSA is closely related to obesity [2,3]. The syndrome is associated with a significant morbidity and mortality. Indeed, excessive daytime sleepiness is responsible not only for impaired quality of life and neurocognitive performance [4], but also for road traffic accidents [5]. It addition, it has been proven that OSA is an independent risk factor for the development of cardiovascular disease, including hypertension, coronary artery disease, congestive cardiac failure, and stroke [6]. Diabetes and metabolic syndrome are also associated metabolic conditions [7,8].

As a consequence, OSA is now considered as a chronic disease leading to increased mortality and is associated with major co-morbidities that can be reversed by treatment. Early diagnosis and therapy are likely to be associated with better outcomes. The efficiency of treatment [9] together with costs related to the untreated disease [10] are additional arguments in favour of early diagnosis and rapid access to sleep medicine centres [11]. OSA diagnosis is classically based on attended in-lab polysomnography (PSG), which remains the reference method. Despite the necessity for qualified technical and medical personal, the number of sleep units has increased exponentially, as reflected by the increase in American Academy of Sleep Medicine (AASM) accredited sleep units in USA which rose from 337 in 1996 to 2461 in June 2012. The demand for sleep studies is also increasing and consequently waiting lists often remain long [12,13].

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Abbreviations

AASM	American Academy of Sleep Medicine
AHI	apnea–hypopnea index
CPAP	continuous positive airway pressure
EEG	electroencephalogram
EMG	electromyogram
EOG	electrooculogram
EU	European Union
H-PSG	home polysomnography
MSLT	multiple sleep latency test
MWT	maintenance of wakefulness test
OSA	obstructive sleep apnea
PSG	polysomnography
RDI	respiratory disturbance index
REM	rapid eye movement
SDB	sleep disordered breathing
SE	sleep efficiency
SWS	slow wave sleep
TM-PSG	telemonitored polysomnography
TST	total sleep time

To overcome this problem, many simplified sleep recording devices have been developed and are now widely used to shorten the delay in sleep disordered breathing (SDB) diagnosis and to decrease the related costs [14]. Recently, the AASM issued new recommendations concerning type 3 and 4 recording devices (type 3 corresponds to limited channel devices, usually 4–7 channels whereas type 4 only includes one or two channels with oximetry as one of them [15]): "*Portable monitoring may be used as an alternative to PSG for the diagnosis of OSA in patients with a high pre-test probability of moderate to severe OSA. Portable monitoring may be indicated for the diagnosis of OSA patients in whom in-laboratory PSG is not possible (…) and to monitor the response to non-CPAP treatments for sleep apnea*." [14].

The use of these simplified devices offers numerous advantages including increased healthcare accessibility [16], earlier treatment initiation [17], better patient comfort and potential cost-savings [17,18]. Although the waiting time to obtain a sleep test has been reduced there are, however, little current data to support this [19,20].

Type 3 recordings are frequently associated with sensor losses and lead to technically inadequate recordings in 5–30% of the cases that bring about test repetition [17,21]. Other concerns are related to limitations in sleep time evaluation. With type 3, sleep time cannot be precisely assessed and arousals are impossible to score. This problem leads to underestimation of SDB severity [18,22,23]. Another concern is related to the correct distinction between OSA, central sleep apneas and periodic breathing although one study, in stable heart failure patients, showed good accuracy for OSA diagnosis and the ability of the device to assess central and obstructive events correctly [24].

Many studies have compared type 3 monitors with PSG but since they use various sensors and recorders, generalization of the results are difficult to pool for systematic review [22]. Type 3 tools are so heterogeneous that a review of their classification was performed recently to take into account the specificities of the monitors [25].

Despite these limitations these studies have confirmed the overall usefulness of type 3 devices, especially if we focus on the outcome which results in earlier access to treatment for the patient [26].

Although type 3 recording devices have limitations, they are mainly used to rule-in SDB in high-risk patients [27]. Given their low negative predictive value, all negative records require a confirmation PSG [23,27,28].

An alternative to type 3 recordings is the home polysomnography (H-PSG). It offers both the implementation of home centred care for patients and a complete sleep evaluation allowing the possibility of diagnosing a large panel of sleep disorders.

Use of type 2 devices (full unattended PSG [15] or H-PSG) has been a subject of debate for years. It is expensive, complex and time-consuming, but has the advantage of being a complete sleep study (electroencephalogram (EEG), movements, cardiocirculatory), allowing not only OSA diagnosis but also diagnosis of numerous other sleep disorders [29–31]. It is a discovery tool rather than a verification tool which is the case for most of the type 3 devices [27]. To date, the AASM still considers that there remain insufficient data to recommend routine use of H-PSG [29].

These devices are intended to perform as well as attended PSG but in an unattended surrounding, without continuous supervision. A trained sleep technician must perform the hook-up of the device, and this factor limits the wider use of this technique.

In this review, we aimed to assess the role of H-PSG through reviewing current available literature.

Methods

Search strategy and selection criteria

We conducted a bibliographic search of the medical literature in June 2013. Medline and Cochrane Library Plus databases were searched in order to extract randomized trials comparing H-PSG and in-laboratory attended PSG. A common search strategy was applied, using the following search terms: "home polysomnography" or "unattended polysomnography" or "randomized AND home AND polysomnography" or "randomized AND unattended AND polysomnography" to extract accurate English published original papers.

Data extraction

Data extracted from these studies included number of patients, inclusion criteria (symptoms, questionnaires), technical aspects related to PSG (hook-up location, PSG quality, failure rate), OSA severity and accuracy of H-PSG for OSA diagnosis (sensitivity, specificity, positive and negative predictive values, likelihood ratio), sleep parameters, subjective assessment of PSG and cost data.

Results

At the present time, six prospective randomized crossover trials comparing home unattended PSG (H-PSG) and in-lab attended PSG, totalling 369 patients, have been published [32–37]. Detailed results of these studies are given in Tables 1and 2.

Four studies [34–37] aimed to compare H-PSG and in-lab attended PSG for OSA diagnosis. In three of the studies included [34,36,37], the majority of the patients were middle-aged obese males, clinically suspected of suffering from OSA, and complaining of excessive daytime sleepiness. In the study conducted by Iber et al. [35], a cohort without pre-existing sleep-clinic evaluation was screened for sleep complaints by a sleep questionnaire, in order to identify a specific pool (50% women, 67% snorers, 50% subjects 40–60 y and 50% subjects >60 y), such that the target population was different and included less severe SDB than in the other studies.

A fifth study [32] included patients requiring a polysomnography, regardless of suspected diagnosis.

The last study was designed to compare sleep quality at home and in the sleep lab before multiple sleep latency test (MSLT) and

Table 1
Results of prospective randomized crossover trials comparing home unattended polysomnography and in-lab attended polysomnography.

Authors (year of publication)	Subjects	Inclusion criteria	Polysomnograph	Hook-up location	Failure rate Lab/home	Scoring	Patient preference Lab/home	Costs Lab/home
Fry et al. (1998) [32]	$N = 77$ 49 M Age: 49 y	Adults requiring PSG	Lab: Gras Model 78D polygraph (one EEG) Home: DHSS (four EEG)	Lab–Lab	0%/4%	Manual	64%/34%	NA
Kingshott et al. (2000) [33]	$N = 16$ 14 M Age: 51 y ESS: 13	Living in city boundary ESS >8 or 2 other major symptoms of SAHS	Home and Lab: Compumedics PS2 (two EEG) No respiratory assessment at home	Lab–Home	NR	Manual	NA	NA
Portier et al. (2000) [34]	$N = 103$ 82% M Age: 52 y ESS: 13 BMI: 31 kg/m^2	Possible OSA, living "not too far"	Home: Minisomno (two EEG) Lab: Respisomnographe (two EEG)	Lab–Lab	5%/20%	Manual	48%/28%	Direct costs of PSG: 308€/153€
Iber et al. (2004) [35]	$N = 76$ Age: 57 y ESS: 8 BMI: 31 kg/m^2	Pool of 50% F, 67% snorers, 50% 40–60 y, 50% >60 y	Home and Lab: Compumedics PS2 (two EEG)	Lab–Home	Global failure rate: 8%	Manual		
Campbell et al. (2011) [36]	$N = 31$ 24 M Age: 49 y ESS: 11 BMI: 31 kg/m^2	Clinical suspicion of OSA	Lab: S-series Compumedics (two EEG), Home: Siesta Compumedics (two EEG)	Lab–Home	0%/7%	Manual	25%/50%	Estimated cost-savings of 25% for home-PSG
Bruyneel et al. (2011) [37]	$N = 66$ 39 M Age: 49 y ESS: 10 BMI: 30 kg/m^2	Clinical suspicion of OSA	Home: Pamela (five EEG) Lab: Brainnet (five EEG)	Lab–Home	2%/5%	Manual	21%/67%	Direct costs of PSG + hospital stay: 1057€/268€

BMI: body mass index, DHSS: DigiTrace Home Sleep System, EEG: electroencephalogram, ESS: Epworth sleepiness scale, F: female, lab: sleep laboratory, M: male, NR: not reported, OSA: obstructive sleep apnea, PSG: polysomnography, SAHS: sleep apnea–hypopnea syndrome.

maintenance of wakefulness test (MWT) in patients suspected of OSA [33].

The main findings of these studies were that H-PSG was technically reliable and allowed good OSA diagnosis accuracy. The quality and duration of patients' sleep tended to be better at home.

H-PSG for sleep disorders diagnosis

Accuracy of H-PSG for OSA diagnosis

It must be stressed that among the six analyzed studies, one was not designed to detect OSA in unattended settings but to compare sleep quality at home and in the sleep lab before objective daytime sleepiness assessment [33].

The analysis is then based on the results of five studies [32,34–37].

Comparing mean apnea–hypopnea index (AHI) recorded during sleep lab PSG and H-PSG, results were globally similar in several studies [32,34,35,37] even if sensitivity and specificity was not evaluated in all studies (Table 2).

In the study by Campbell et al. [36], for an AHI cut-off value of 10, results were very good, with a sensitivity of 91% and a specificity of 89%. Similarly, Bruyneel et al. [37] highlighted a diagnostic sensitivity and specificity of H-PSG using a cut-off of AHI $\geq$20 of respectively 76 and 85%.

In the research by Iber et al. [35], the median respiratory disturbance index (RDI) was not different at home and in the sleep lab (12.4 vs 9.5) but was quite low, as expected from the targeted population. Intraclass correlation coefficients were respectively 0.77 and 0.75 for RDI 3% and RDI 4%. They also described a trend toward more respiratory events detected at home for RDI <20, and less for RDI >20. Bruyneel et al. [37] observed the same trends but the opposite was observed in another study [36] for AHI >26: there were more severe cases at home in case of moderate to severe OSA.

Globally, H-PSG tended to moderately overestimate sleep apnea severity for mild to moderate OSA and to underestimate severity for more severe cases [35,37]. These disparities could be explained by the night-to-night variability, which is estimated between 10 [38] and 20% [39].

Night-to-night variability can be related to factors such as body position (more supine sleep in sleep lab [32]), medication and alcohol habits, nasal congestion, sleep architecture (more frequent arousals and more sleep stage changes in the sleep lab could result in arousal-associated respiratory events [35]).

The role of the body position is however difficult to confirm since it was evaluated in only two [36,37] of the six studies. In these two studies, similar time was spent supine in both settings.

H-PSG for other sleep diagnosis

Unlike type 3 sleep testing devices H-PSG, by recording neurologic parameters, (EEG, EOG, EMG) offers a greater possibility of diagnosing sleep disorders. Indeed, in these six prospective randomized studies, apart from OSA diagnosis, periodic leg movements have been detected [32,37] affecting 31%–47% of the patients. We have however, to mention that the majority of the studies included patients suspected of OSA and was not designed to diagnose other sleep disorders.

Sleep quality during H-PSG

As patients slept in familiar surroundings at home, sleep seemed to be more representative than in the sleep lab. In general they slept better at home, as demonstrated in three of the six prospective studies through sleep efficiency (SE) analysis: Bruyneel et al. [37] showed that SE was better at home than in the sleep lab (82 vs 75%) and similar observations were made by Iber et al. [35]: median

Table 2
Results of prospective randomized crossover trials comparing home unattended polysomnography and in-lab attended polysomnography.

Authors	OSA severity Lab/home	TST (min) Lab/home	SE (%) Lab/home	% REM sleep Lab/home	% SWS Lab/home	Time supine Lab/home	Sensitivity for OSA diagnosis	Specificity	PPV	NPV
Fry et al. [32]	AHI: 29/30	412/373*	80/79	57/60	41/40	NA	NA	NA	NA	NA
Kingshott et al. [33]	AHI: 35/NA	343/362	71/81*	15/20*	11/16*	NA	NA	NA	NA	NA
Portier et al. [34]	RDI: 26/23 Mean RDI difference Home−Lab: −2.9	305/334*	NR	10/12	8/8	NA	NA	NA	NA	NA
Iber et al. [35]	RDI 3%: 10/12	318/375*	82/86*	20/21*	17/15	NA	For RDI 3% > 10: 64%	75%	69%	88%
Campbell et al. [36]	AHI: 35/27*	NR but similar	84/87	17/16	NR	36/41% TST	For AHI > 15: 94%	77%	LHR + 4.1	LHR − 0.08
Bruyneel et al. [37]	AHI: 26/23 Mean AHI difference Lab−home: 3.3	365/412*	75/82*	16/19*	25/24	209/187 min	For AHI > 20: 76%	85%	88%	73%

AHI: apnea–hypopnea index, lab: sleep laboratory, LHR: likelihood ratio, NA: not assessed, NPV: negative predictive value, NR: not reported, RDI: respiratory disturbance index, OSA: obstructive sleep apnea, PPV: positive predictive value, REM: rapid eye movement, SE: sleep efficiency, SWS: slow wave sleep, TST: total sleep time, *: p Value<0.05.

SE of 86% vs 82%, and by Kingshott et al. [33] with values of 81% vs 71%.

Where this information was available, it must be stressed that light-on and light-off times at home were not imposed by the research teams but decided by the patient, who had to install an oximetry probe and start the recording [32], or to note the light-off time [33,37].

Unfortunately, for the last three studies [34–36], no information is given about the measurement of the time in bed in the home setting.

In three of the series total sleep time (TST) also improved significantly at home [34,35,37], because patients effectively slept longer and better and/or because they were not woken up by the sleep lab nurse at a definite time, which was the case in two of the studies [34,37].

However, Fry et al. [32] found that TST was significantly shorter at home without obvious explanation. In this study, patients could sleep till their spontaneous awakening in the sleep lab. At home, they started the recordings themselves at bedtime and stopped it when they woke. We do not know if patients experienced problems starting and stopping the recordings but this could be a potential explanation for the lower TST at home. Kingshott and Douglas and Campbell and Neill [33,36] results showed TST was similar at home and in the sleep lab.

Regarding sleep architecture at home compared to in-lab, the amount of REM sleep was increased in three studies [33,35,37], and slow wave sleep (SWS) percentage was higher in one study [33]. In this last study, sleep fragmentation was also significantly lower at home.

Taken together, these findings reflect a better sleep quality when patients sleep in their usual environment.

Quality of recordings during H-PSG

Generally, at home, the problematic probeslikely to lead to analysis difficulties if they are lost during the night are nasal cannula, abdominal and chest effort, and oximetry sensors [32,34,36,40]. As an example, the results of Portier et al. [34], showed an 11% poor airflow signal at home vs only 2% in the sleep lab. However, in these studies, despite more frequent losses of nasal cannula, abdominal and chest effort and oximetry signals, adequate recordings were obtained respectively in 79–96%, 79–100%, 90–100% and 93–98% of the cases and the values can still be considered as optimal in order to interpret PSG.

It must be stressed that hook-up location can widely influence the recording's quality. Indeed, in two studies [32,34], PSG hook-up was performed in the hospital and patients returned home with the device already fitted. This method is convenient for the technical sleep lab team but can subsequently lead to a larger PSG failure rate, reaching up to 20% in the study by Portier et al. [34]. However, when the patient was fitted at home the failure rate decreased to acceptable values between 5 and 8% [35–37].

The number of EEG sensors is another parameter which can have some bearing on the failure rate of neurological recording. In the majority of studies, technicians are working with two leads [33–36], a condition which results into an increased risk of losing the EEG data completely. Fry et al. [32] and Bruyneel et al. [37] worked respectively with four and five leads at home, in order to minimize this potential risk of failure. The success rate of H-PSG increased in this case (respectively 96 and 95%) when compared to recordings obtained with two EEG leads (80–93% [33–36]).

Cost of H-PSG

In eliminating the need for hospitalization H-PSG could potentially result in important cost-savings but unfortunately, few data related to formal cost analysis (taking into account staff costs, sleep lab costs, technical costs, and travel costs) are available. The majority of the studies give an up-front list of the payments in their own sleep lab conditions [34,36,37], but PSG costs are also related to local reimbursement policies which vary greatly from country to country. In their study Portier et al. [34], found the cost of PSG was 307.6€ in the lab and only 152.5€ at home. They did not however, take into account the cost of repeated PSG in case of failure.

Campbell et al. [36] estimated that H-PSG costs 75% of in-lab procedure, when adjusted for failed recordings. Bruyneel et al. [37] appraised that payments were substantially higher in the lab if hospitalization costs were included (1057€ vs 268€).

Discussion

Through analysis of these six prospective, randomized, crossover trials comparing H-PSG and in-lab PSG, we can conclude that this complex but comprehensive sleep assessment tool is reliable and accurate to diagnose OSA, in a comfortable way for the patients ("home sweet home"), where quality of sleep tends to be better. Failure rate of the recordings is low despite the absence of supervision.

However, some specific aspects of the technique in this particular condition must be discussed.

Theoretically, H-PSG may offer advantages over type 3 recordings. Indeed, whatever the suspected sleep problem, H-PSG should offer a definitive evaluation of patients with sleep-related complaints, eliminating the need for repeated sleep tests in case

of negative results. Unlike type 3 recordings, H-PSG can also be offered to OSA-suspected patients with co-morbidities [34]. Finally, several studies have demonstrated the use of the device for other sleep disorders: periodic leg movements during sleep [29,37], central sleep apneas [30], circadian rhythm disorders [31], sleep bruxism [41], insomnia [26].

H-PSG does, however, demonstrate some disadvantages when compared to PSG in the laboratory. For example H-PSG is not suitable when we need to couple the night recording with video (parasomnias, nocturnal epilepsy and complex behavioural nighttime disorders) or C02 transcutaneous measurement (hypoventilation syndromes). Following H-PSG, it appears difficult to perform daytime specific tests (MSLT, MWT, Osler Test) in case of hypersomnolence disorders assessment [42].

For these specific cases, at the present time, H-PSG does not seem to be a sufficient diagnostic tool.

There is also a slight discrepancy between the severity of OSA at home and in the sleep lab. Globally, H-PSG tends to moderately overestimate sleep apnea severity for mild to moderate OSA and to underestimate severity for more severe cases [35,37]. Apart from night-to-night variability, this fact can be interpreted in different ways. Attended in-lab PSG is considered as the "gold standard" method, but assuming that the patient sleeps in an artificial (and sometimes unpleasant) environment, resulting in increased sleep fragmentation [33], the home-recorded OSA index probably, reflects the true severity of OSA more accurately. To that extent, H-PSG might be considered as the true gold standard.

Regarding H-PSG recording quality and patient comfort, the set-up location of H-PSG seems to be an essential point to achieve both objectives. Placing probes at home is more expensive, but seems to allow better quality PSG recordings [35–37]. However, improved quality could also be explained by other factors (technical expertise, number of EEG sensors, patient behaviour,…), but unfortunately, at this time, no studies comparing the hook-up location (at home vs in the sleep lab) and its impact on H-PSG quality have been conducted.

Cost analysis is also a key point when analysing H-PSG. To date, few complete cost analyses are available [43]. It is however, extremely complex to perform a formal cost analysis as it requires the following to be taken into account: staff costs (cost of the technician to work in patients' homes, costs related to PSG scoring and reporting), sleep lab costs (purchase of home polysomnograph, robustness of devices, maintenance costs, replacement of broken sensors, reliability and life of batteries, consumable items, update of computer programs), travel costs (including car insurance) and the potential cost of lost working days following mainly in-lab PSG. It is also difficult to compare the cost of a sleep technician working a night shift in the hospital and able to attend up to four PSG [44] with the cost of a day shift technician who may only set-up one to two H-PSG per day but will be driving around for a variable period of time, sometimes in arduous conditions (traffic jam, snow,…). However, as suggested by several studies [34,36,37] the H-PSG cost is likely to be less than in-lab PSG cost, notably when hospitalization costs are taken into account [37].

What are the current and future developments?

Potential future developments include the use of assistive technology and telemedicine to allow real-time remote monitoring of home unattended PSG.

Indeed, information and communication technologies allow data transmission from the patient's home to hospital, for diagnosis or therapeutic and follow-up purposes, avoiding patient displacement, something welcomed by those patients who live some distance from the hospital [45].

As mentioned above, the major problem encountered with home sleep testing devices is the potential loss of data, observed with H-PSG (4.7–20%) [30] as well as with type 3 recordings (up to 24%) [17], leading to less cost-savings than expected.

Recently, in order to enhance the quality of the home-based polysomnography, real-time telematic data transmission has been tested. A research team, in Cleveland, performed an interesting preliminary study in 10 fibromyalgic patients. They described an easily deployable home monitor, PSG@Home, which allows complete sleep evaluation in the patients' homes under direct remote supervision of a sleep specialist. The PSG is transmitted by a cell phone in real-time. All ten studies were successful and generated high-fidelity recording [46].

Gagnadoux et al. [47] studied 99 patients, in a prospective randomized crossover trial, who underwent home unattended and in-hospital unattended but telemonitored polysomnography (TM-PSG). The TM-PSG was recorded in medical units of two peripheral hospitals. The specialized technicians of the sleep lab checked the quality of the recordings every 30 min and were instructed to ask the nurses from the two distant hospitals to replace electrodes giving faulty signals. Recordings took place on two consecutive nights. For H-PSG, hook-up was performed in the sleep lab. Failure rate was 11% for TM-PSG vs 23% for H-PSG. 13 TM-PSG required technical interventions to replace lost sensors, but in four cases, the nurse of the medical unit was not able to correct the problem. This means that without telemonitoring, failure rate would have been 19%, but was reduced to 11% with remote supervision. A question raised by this study is the high failure rate of unattended H-PSG. Similar results have been shown by Portier et al. [34] which can again be related to sleep lab set-up rather than home set-up. In the latter study, the medical team performed a very precise cost analysis and concluded that telemedicine was more effective (half the number of failures) but very expensive ($244 vs $153 for home-PSG) [43]. Bruyneel et al. also performed a pilot study using the Sleepbox® device to obtain real-time remote supervision of H-PSG, from the sleep lab [44]. Sleepbox® is a wireless system able to communicate with the Dream®. The sleep lab nurse performed a remote discontinuous monitoring of the H-PSG every hour. In case of sensor loss, she was able to call the patient, who had previously been trained, to replace the sensors correctly.

90% of the recordings were of excellent quality. Among the 10% PSG failure rate, one failure was due to the Dream® (batteries), and one was related to recording of poor quality. For sensor losses, two Skype® interventions were required, resulting in readjustment of the defective probes. H-PSG signal visualization was possible in 90% of cases but the Skype®connection was problematic in 19% of cases. However, patients could be reached by phone to solve the problem.

On the basis of these results, real-time remote attended H-PSG seems feasible and may be an interesting prospect in decreasing the failure rate of home sleep studies, even if some technical aspects need to be improved.

There are some barriers related to the implementation of telemedicine in the field of sleep medicine.

First of all, the telemonitoring devices are very complex and the heterogeneity of the systems is huge, with potential compatibility problems with the other computer programs used in hospitals.

Secondly, the high cost (patients' home must be equipped with a computer and an Internet connection, high specifications of computer programs) will slow the implementation of these systems, and no specific reimbursement policy is foreseen. However, investigations using solely the integrated circuits available on the market (mobile telephony) are conducted to simplify access to these technologies for both patients and hospitals [48,49].

Lastly, there are also problems related to privacy protection and security of medical data transmission and the European Union (EU) commission is currently working to adapt existing rules to face

e-health needs [50]. Further research will then be required to establish the place of telemedicine in SDB diagnosis.

Conclusion

H-PSG is a comprehensive sleep assessment tool which is reliable in the diagnosis of OSA in a way which is beneficial to the patient whilst demonstrating a good technical performance. The device can be used to rule-in and rule out OSA in suspected patients, even in presence of co-morbidities. It is an interesting option in patients with negative type 3 sleep testing, or in disabled patients, unable to use type 3 devices correctly. H-PSG could be more widely employed in the assessment of other sleep disorders, such as periodic leg movements during sleep, circadian rhythm disorders, sleep bruxism and insomnia, but these indications must be confirmed by further larger studies.

The widespread use of H-PSG is limited by its complexity and costs. The costs are largely related to the necessity for specialist technicians to visit patients' homes.

Telemedicine is developing and studies performed with remotely attended H-PSG, in order to enhance the quality of the recordings, are encouraging. The ideal future would be to simplify technical aspects of H-PSG, allowing the patient to set-up the recording device at home and to couple it with remote monitoring in order to obtain optimum quality.

Practice points

H-PSG is a complete sleep assessment tool, indicated:

- To rule-in and rule out OSA diagnosis and which, unlike type 3 devices, can be used in OSA-suspected patients with co-morbidities.
- To assess other sleep disorder diagnoses: further studies are needed to define the role of H-PSG in these areas.
- Telemedicine can improve H-PSG quality by offering real-time remote monitoring.

Research agenda

In the future, we need:

- To simplify the technical aspects of H-PSG and to specify the role of telemonitoring for remotely-attended recordings.
- To perform complete cost-effectiveness analyses of H-PSG (± telemonitoring).
- To determine the effect of hook-up location on H-PSG's quality.
- To develop portable infrared video-PSG that could be able to offer more complete sleep assessment at home.

References

[1] Guilleminault C, Tilkian A, Dement WC. The sleep apnea syndromes. Annu Rev Med 1976;27:465–84.
[2] Ogden CL, Carroll MD, Curtin LR, McDowell MA, Tabak CJ, Flegal KM. Prevalence of overweight and obesity in the United States, 1999–2004. J Am Med Assoc 2006;295:1549–55.
[3] Young T, Peppard PE, Gottlieb DJ. Epidemiology of obstructive sleep apnea: a population health perspective. Am J Respir Crit Care Med 2002;165:1217–39.
[4] Engleman HM, Martin SE, Douglas NJ. Compliance with CPAP therapy in patients with the sleep apnoea/hypopnoea syndrome. Thorax 1994;49:263–6.
[5] Terán-Santos J, Jiménez-Gómez A, Cordero-Guevara J. The association between sleep apnea and the risk of traffic accidents. Cooperative Group Burgos-Santander. N Engl J Med 1999;340:847–51.
[6] McNicholas WT. Diagnosis of obstructive sleep apnea in adults. Proc Am Thorac Soc 2008;5:154–60.
[7] Punjabi NM, Ahmed MM, Polotsky VY, Beamer BA, O'Donnell CP. Sleep-disordered breathing, glucose intolerance, and insulin resistance. Respir Physiol Neurobiol 2003;136:167–78.
[8] Wang X, Bi Y, Zhang Q, Pan F. Obstructive sleep apnoea and the risk of type 2 diabetes: a meta-analysis of prospective cohort studies. Respirology 2013;18:140–6.
[9] Marti S, Sampol G, Munoz X, Torres F, Roca A, Lloberes P, et al. Mortality in severe sleep apnoea/hypopnoea syndrome patients: impact of treatment. Eur Respir J 2002;20:1511–8.
[10] Leger D, Bayon V, Laaban JP, Philip P. Impact of sleep apnea on economics. Sleep Med Rev 2012;16:455–62.
[11] Simon S, Collop NA. Latest advances in sleep medicine. Chest 2012;142:1645–51.
[12] Flemons W, Douglas NJ, Kuna ST, Rodenstein DO, Wheatley J. Access to diagnosis and treatment of patients with suspected sleep apnea. Am J Respir Crit Care Med 2004;15:668–72.
[13] Masa Jimenez JF, Barbé Illa F, Capote Gil F, Chiner Vives E. Resources and delays in the diagnosis of sleep apnea-hypopnea syndrome. Arch Bronconeumol 2007;43:188–98.
*[14] Collop NA. Clinical guidelines for the use of unattended portable monitors in the diagnosis of obstructive sleep apnea in adult patients. J Clin Sleep Med 2007;3:737–47.
[15] Standards of Practice Committee of the American Sleep Disorders Association. Practice parameters for the use of portable recording in the assessment of obstructive sleep apnea. Sleep 1994;26:907–13.
[16] Collop NA. Portable monitoring for the diagnosis of obstructive sleep apnea. Curr Opin Pulm Med 2008;14:525–9.
*[17] Masa JF, Corral J, Pereira R, Duran-Cantolla J, Cabello M, Hernández-Blasco L, et al. Effectiveness of home respiratory polygraphy for the diagnosis of sleep apnoea and hypopnoea syndrome. Thorax 2011;66:567–73.
[18] Ghegan MD, Angelos PC, Stonebraker AC, Boyd Gillepsie M. Laboratory versus portable sleep studies: a meta-analysis. Laryngoscope 2006;116:859–64.
[19] Chai-Coetzer CL, Antic NA, Rowland LS, Reed RL, Esterman A, Catcheside PG, et al. Primary care vs specialist sleep center management of obstructive sleep apnea and daytime sleepiness and quality of life: a randomized trial. J Am Med Assoc 2013;309:997–1004.
[20] Corral-Penafiel J, Pepin JL, Barbe F. Ambulatory monitoring in the diagnosis and management of obstructive sleep apnoea syndrome. Eur Respir Rev 2013;22:312–24.
[21] Golpe R, Jimenez A, Carpizo R. Home sleep studies in the assessment of sleep apnoea-hypopnoea syndrome. Chest 2002;122:1156–61.
[22] Flemons WW, Littner MR, Rowley JA, Gay P, Anderson WM, Hudgel DW, et al. Home diagnosis of sleep apnea: a systematic review of the literature. Chest 2003;124:1543–79.
[23] Trikalinos TA. Home diagnosis of obstructive apnea-hypopnea syndrome. Rockville (MD): Agency for Healthcare Research and Quality (US); August 2007.
[24] Quintana-Gallego E, Villa-Gil M, Carmona-Bernal C, Botebol-Benhamou G, Martinez-Martinez A, Sanchez-Armengol A, et al. Home respiratory polygraphy for diagnosis of sleep disordered breathing in heart failure. Eur Respir J 2004;24:679–86.
[25] Collop NA, Tracy SL, Kapur V, Mehra R, Kuhlmann D, Fleishman SA, et al. Obstructive sleep apnea devices for out-of-center (OOC) testing: technology evaluation. J Clin Sleep Med 2011;7:531–48.
[26] Coryell VT, Ziegelstein RC, Hirt K, Quain A, Marine JE, Smith MT. Clinical correlates of insomnia in patients with acute coronary syndrome. Int Heart J 2013;54:258–65.
[27] Hirshkowitz M, Sharafkhaneh A. Comparison of potable monitoring with laboratory polysomnography for diagnosing sleep-related breathing disorders: scoring and interpretation. Sleep Med Clin 2011;6:283–92.
[28] American Sleep Disorders Association Report. Practice parameters for the indications for polysomnography and related procedures. Sleep 1997;20:406–22.
*[29] Kushida CA, Littner MR, Morgenthaler T, Alessi CA, Bailey D, Coleman Jr J, et al. Practice parameters for the indications for polysomnography and related procedures: an update for 2005. Sleep 2005;28:499–521.
[30] Mehra R, Stone KL, Varosy PD, Hoffman AR, Marcus GM, Blackwell T, et al. Nocturnal arrhythmias across a spectrum of obstructive and central sleep-disordered breathing in older men: outcomes of sleep disorders in older men (MrOS sleep) study. Arch Intern Med 2009;169:1147–55.
[31] Jean-Louis G, Kripke DF, Assmus JD, Langer RD. Sleep-wake patterns among postmenopausal women: a 24-hour unattended polysomnographic study. J Gerontol A Biol Sci Med Sci 2000;55:M120–3.

* The most important references are denoted by an asterisk.

*[32] Fry JM, DiPhillipo MA, Curran K, Goldberg R, Baran AS. Full polysomnography in the home. Sleep 1998;21:635–42.

*[33] Kingshott N, Douglas NJ. The effect of in-laboratory polysomnography on sleep and objective daytime sleepiness. Sleep 2000;23:1109–13.

*[34] Portier F, Portmann A, Czernichow P, Vascaut L, Devin E, Benhamou D, et al. Evaluation of home versus laboratory polysomnography in the diagnosis of sleep apnea syndrome. Am J Respir Crit Care Med 2000;162:814–8.

*[35] Iber C, Redline S, Kaplan Gilpin AM, Quan SF, Zhang L, Gottlieb DJ, et al. Polysomnography performed in the unattended home versus the attended laboratory setting-Sleep Heart Health Study Methodology. Sleep 2004;27:536–40.

*[36] Campbell AJ, Neill AM. Home set-up polysomnography in the assessment of suspected obstructive sleep apnea. J Sleep Res 2011;20:207–13.

*[37] Bruyneel M, Sanida C, Art G, Libert W, Cuvelier L, Paesmans M, et al. Sleep efficiency during sleep studies: results of a prospective study comparing home-based and in-hospital polysomnography. J Sleep Res 2011;20:201–6.

[38] Stepnowsky Jr CJ, Orr WC, Davidson TM. Nightly variability of sleep-disordered breathing measured over 3 nights. Otolaryngol Head Neck Surg 2004;131:837–43.

[39] Quan SF, Griswold ME, Iber C, Nieto FJ, Rapoport DM, Redline S, et al. Short-term variability of respiration and sleep during unattended non laboratory polysomnography – the Sleep Heart Health Study. Sleep 2002;25:843–9.

[40] Kapur VK, Rapoport DM, Sanders MH, Enright P, Hill J, Iber C, et al. Rates of sensor loss in unattended home polysomnography: the influence of age, gender, obesity, and sleep-disordered breathing. Sleep 2000;23:682–8.

[41] Doering S, Boeckmann JA, Hugger S, Young P. Ambulatory polysomnography for the assessment of sleep bruxism. J Oral Rehabil 2008;35:572–6.

[42] Littner MR, Kushida C, Wise M, Davila DG, Morgenthaler T, Lee-Chiong T, et al. Practice parameter for clinical use of the multiple sleep latency test and the maintenance of wakefulness test. Sleep 2005;28:113–21.

[43] Pelletier-Fleury N, Gagnadoux F, Philippe C, Rakotonanahary D, Lanoé JL, Fleury B. A cost-minimization study of telemedicine. The case of tele-monitored polysomnography to diagnose obstructive sleep apnea syndrome. Int J Technol Assess Health Care 2001;17:604–11.

[44] Bruyneel M, Van den Broecke S, Libert W, Ninane V. Real-time attended home-polysomnography with telematic data transmission. Int J Med Inform 2013;82:696–701.

[45] Nangalia V, Prytherch DR, Smith GB. Health technology assessment review: remote monitoring of vital signs-current status and future challenges. Crit Care 2010;14:233.

[46] Kayyali HA, Weimer S, Frederick C, Martin C, Basa D, Juguilon JA, et al. Remotely attended home monitoring of sleep disorders. Telemed J E Health 2008;14:371–4.

*[47] Gagnadoux F, Pelletier-Fleury N, Philippe C, Rakotonanahary D, Fleury B. Home unattended vs hospital telemonitored polysomnography in suspected obstructive sleep apnea syndrome: a randomized crossover trial. Chest 2002;121:753–8.

[48] Dellaca R, Montserrat JM, Govoni L, Pedotti A, Navajas D, Farré R. Telemetric CPAP titration at home in patients with sleep apnea-hypopnea syndrome. Sleep Med 2011;12:153–7.

[49] Farré R. The future of telemedicine in the management of sleep-related respiratory disorders. Arch Bronconeumol 2009;45:105–6.

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